EEG/MEG evidence for multiple supratemporal sources of the auditory middle-latency components

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1 Introduction

The organization of the human auditory cortex has been described to be parcelled into more than 12 areas organized in 3 regions : the core line region, containing the primary auditory cortex (PAC) in the most anterior Heschl gyrus (HG or H1), surrounded by the belt region, itself boarded laterally by the parabelt region [1–2].

In an attempt to estimate non invasively the chronological sequence of activation of these areas, EEG and MEG are good candidates for they provide ms-range time precision.

The auditory evoked cortical responses seen by these techniques start around 20 ms after the stimulus onset. The earliest, peaking before 80 ms, are called middle-latency components, and are followed by long-latency components in the time-range 80–300 ms. Because the middle-latency components are small signals difficult to be recorded on the scalp, their sources have not yet been clearly identified on the individual anatomy. Few studies using MEG [3–6] or intracerebral recordings [7,8] have so far suggested that MLC sources are located in the PAC along Heschl gyrus.

The goal of this investigation was to obtain further anatomical and electrophysiological data on the supratemporal cortical structures first activated by simple stimulations with pure tone-bursts. In a test-retest paradigm with simultaneously recorded EEG and MEG, identification of MLC sources has been performed by use of realistic head models based on individual MRIs.

2 Methods

2.1 Subjects and stimuli

Six right-handed subjects (one male and five females, aged 24 to 30 years) took part in this experiment, which was repeated 3 times for three of them, and duplicated for the other three. These repetitions (sessions), were carried out on different days. Subjects were presented 8000 1-kHz pure tones (rise, plateau, and decay times of 3, 20, and 20 ms, respectively) to the right ear at 60 dB HL (sensitive level) with a random ISI ranging between 150 and 350 ms.

2.2 Data acquisition and processing

MEG- (BTi, 37-channel gradiometer) and EEG-continuous data (Neuroscan, 32 channels) were recorded simultaneously (bandwidth: 0.16 to 400Hz, sampling rate: 1043 Hz) and stored for off-line analysis. Because the MEG device covered only one hemisphere at a time, each session consisted of two measurements, one for each hemisphere. The order of recorded hemisphere was balanced between sessions.

During the measurement sessions, subjects were watching a self-selected cartoon, comfortably lying on the side opposite to the MEG-recorded hemisphere, with their head lying on a mould ensuring stable fixation throughout the whole measurement. Data sets in which the relative position between the head and the MEG instrument changed by more than 1 cm were discarded from further analysis (this occurred 3 times over 30 measurements). For the 27 accepted measurements, the head movement was 4.3 mm on average.

Trials with EOG artifacts were rejected, using a threshold for MEG and EEG/EOG signals of 3000 fT and 150 µV, respectively. Artifact-free trials were averaged over a 1300-ms period, including 600-ms baseline. These averaged epochs were baseline-corrected, using the [-50 ms, 0 ms] time window, digitally band-pass filtered between 3 Hz (12dB/octave) and 150 Hz (24 dB/octave), and finally again baseline-corrected using the same 50-ms window.

2.3 Sensors and electrodes registration

For each subject, a full head-shape including eye globe contours was obtained before each EEG/MEG session (figure 1a). Using a procedure proposed by

Schwartz et al. [9], the sensors and electrodes were registered onto the anatomy by matching this full head-shape with the scalp surface segmented from MRIs (figure 1b).

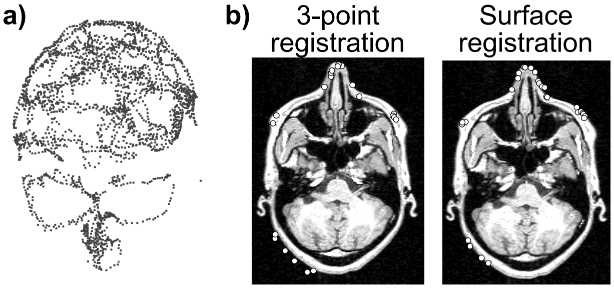

Figure 1**:** **(a)** *individual head-shape. (b) The registration of the head-shape (little circles), and thus that of the sensors and electrodes, is better using all head-shape points (right) than only the 3 classical landmarks nasion and left and right tragus (left).*

2.4 Source localization

Individual realistic boundary element models (BEM) were constructed for each subject from contour stacks semi-automatically segmented from MRIs [10]. Each BEM consisted of three uniformly meshed surface shells (representing the inner and outer skull and the scalp) with 3.2 triangles/cm^2 (average element edge length of 8.8 mm). For all subjects, a complete model was made of about 8000 triangles and 4000 points (figure 2).

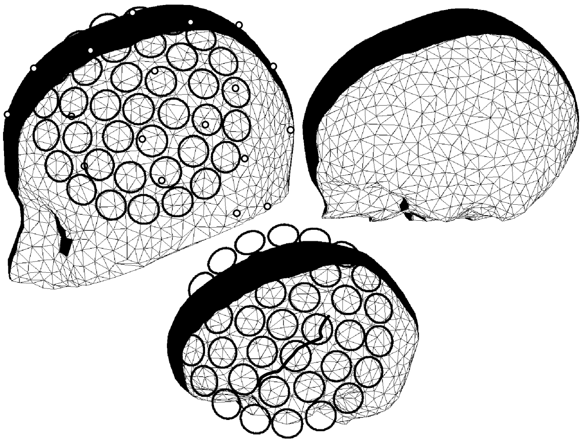

Figure 2**:** *individual realistic head models are shown with the MEG sensos and EEG electrodes. The sylvian fissure is sketched on the inner surface of the model.*

Such models have been recently evaluated on simulations [11], and it was found that the positions of even radially oriented sources could theoretically be retrieved using realistic BEM models.

EEG peaks and troughs on fronto-central electrodes (F3/C3 on the left hemisphere, and F4/C4 on the right hemisphere) were used to individually select the latencies of the different MLC components.

A moving dipole model was applied on MEG data for each hemisphere separately, at each time sample between 0 and 150 ms. For each component, the dipole having the best goodness-of-fit value (gof) within a 2-ms time window around the selected latency was considered as the source of the component. Only sources corresponding to high gof values above 97% were considered for further analysis. For each subject and component, the source positions obtained in the different sessions were averaged.

2.5 Inter-subject registration

For inter-subject statistical analysis of the source coordinates in each hemisphere, all subjects' source positions were registered in a common frame : all subjects' auditory cortices were aligned by matching the center of 3 landmarks (A, B, C) identified from MRIs in the auditory cortex :

Point A : postero-medial terminus of Heschl's gyrus (identified by browsing sagittal slices)

Point B : dorso-lateral edge of the supratemporal gyrus (STG) identified in the same coronal section as A

Point C : rostro-lateral terminus of Heschl's gyrus, where it merges with the STG (identified by browsing sagittal slices)

Additionally, the first Heschl sulcus (HS1) and the lateral aspect of the supratemporal sulcus (STS) were identified from individual sagittal MRIs.

For each subject, the center of the head-coordinate system was translated to the center of gravity of these 3 landmarks. Hence, aligning these coordinate centers across subjects allowed for the registration of the sources and anatomical landmarks (points A,B,C and sulci) of all subjects.

2.6 Statistical analysis of the sources

One-way multivariate statistical analysis (MANOVA, Wilks lambda test) was first performed to account for a global effect of the components on the aligned source positions, and next, post-hoc T^2 tests were used to account for 2-by-2 significant differences between clusters of sources corresponding to the different components.

3 Results

3.1 Components

Four components, corresponding to peaks and troughs on fronto-central electrodes, could be consistently identified from EEG recordings (see figure 3 for a given subject) : Pa peaking around 28 ms, Nb (40 ms), and 2 sub-components of the Pb complex corresponding to 2 clearly distinct peaks at 52 ms (Pb1) and 74 ms (Pb2). The Na component could only be identified in 3 subjects on EEG data, but not on MEG data, and was thus not further evaluated. The latency of each component was determined according to these peaks, and adjusted by a few milliseconds, in order to obtain a stable topography in time.

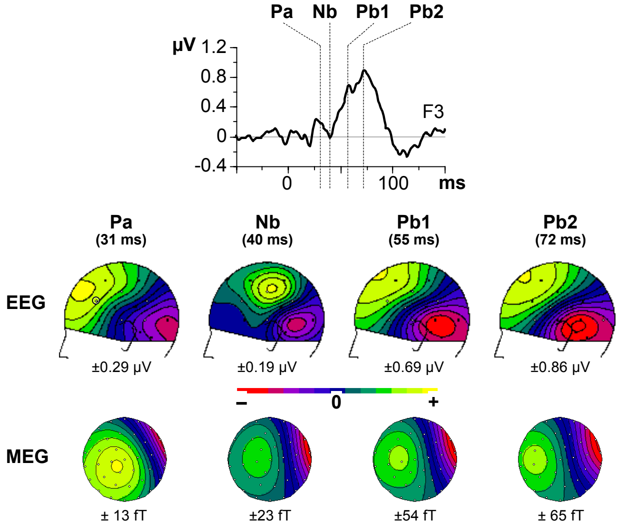

Figure 3: *evoked components identified in one subject for a given session. Top : evoked response collected on the F3 electrode (circle on the most left EEG map). Bottom : EEG and MEG topographies for each component over the contralateral (left) hemisphere.*

3.2 Sources

For each component, we selected the dipole source yielding the best gof value 2 ms around the selected latency. Moreover, sources with gof values lower than 97% were discarded from further analysis. This was mainly the case for the Nb component in the right hemisphere, for which no acceptable sources were obtained in 3 subjects. The accepted sources were averaged across sessions for each subject, then registered with respect to the 3 individual landmarks (see Methods), and finally averaged across subjects.

Figure 4 shows the final mean locations across all subjects for each component with respect to individual HS1 and STS sulci in the left hemisphere.

In the left hemisphere, Pa sources were found on the dorso-postero-medial portion of HS1, whereas Nb and Pb1 sources were localized very laterally within the STG or the upper bank of the STS. Pb2 sources were found on HS1 ventro-antero-laterally from Pa sources. The multivariate statistical analysis revealed a strong effect of the component factor over the source positions ($p<0.0001$) in this hemisphere. Post-hoc T^2 tests showed that the cluster of Pa sources was significantly different from those of Nb ($p=0.003$), Pb1 ($p=0.001$), and Pb2 ($p=0.008$) sources, that Nb sources could be dissociated from Pb2 ($p=0.029$), but not from Pb1 sources ($p>0.6$), and finally that Pb1 sources tended to be different from Pb2 ($p=0.13$). In the right hemisphere (not illustrated), the sources of all components were rather progressively aligned rostro-laterally along HS1 when increasing latency, with Nb sources slightly shifted laterally. The inter-subject variability was higher than in the left hemisphere and the MANOVA showed only a global trend ($p=0.098$), not allowing reliable post-hoc 2-by-2 comparisons of the source clusters.

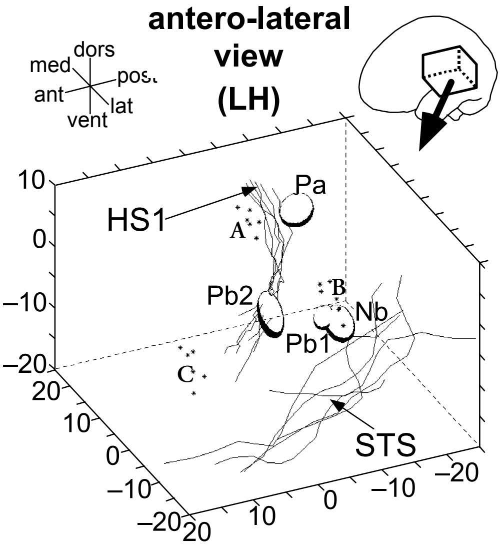

Figure 4: *across-subject mean location of the sources with respect to individual Heschl and supratemporal sulci (HS1 and STS) in the left hemisphere. Auditory cortices of all subjects have been registered by aligning the centers of the ABC landmarks.*

4 Discussion

The areas identified in this study have already been reported activated in several fMRI studies [12,13], however without any temporal information. Here we found a clear spatio-temporal pattern of early activations within the auditory cortex, including the PAC and secondary areas (STG/STS).

Our results are in accordance with animal studies reporting the involvement of secondary areas in the generation of MLCs [14,15]. They also agree with previous invasive human intracerebral recordings [16,17] revealing early activation of the STG around 40 ms, which origin can be attributed either to possible cortico-cortical connections between the primary auditory cortex and STG as recently observed in humans [17], or to parallel thalamo-cortical routes to the auditory cortex [2]. Several studies in cats [18] and guinea pigs [19] indeed support that the MLCs originate from different generating systems including primary and secondary thalamo-cortical routes.

Acknowledgements

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